Roost caves of the Eastern Horseshoe Bat *Rhinolophus megaphyllus* Gray, 1834 (*Chiroptera: Rhinolophidae*) in the Pilliga forest in northern inland New South Wales, Australia

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ABSTRACT

Seven sandstone caves in the Pilliga forest, in northern inland New South Wales, were identified as diurnal roosting sites used by the Eastern Horseshoe Bat *Rhinolophus megaphyllus*. The population of *R. megaphyllus* in the Pilliga forest is considered to be of regional conservation significance, being on the western inland edge of the species' Australian distribution in a bioregion predominantly devoted to agriculture. Data derived from diurnal counts of roosting bats in the seven caves over the period 2007-2014 is presented here, together with a description of the caves and a review of the spatial and temporal distribution of local records of the species. *Rhinolophus megaphyllus* is an uncommon resident in the Pilliga forest with the core area of distribution coinciding with the most topographically rugged areas in the south-eastern and eastern parts of the forest. The roosting caves were between 10 and 30 m deep with bats generally occupying the darkest available recesses. All of the caves had either restricted entrances into or restricted dimensions within the roosting chamber. The maximum colony size noted during diurnal counts was nine bats, although observations of bats emerging at dusk indicated that under-estimation during diurnal counts was likely. Roosting *R. megaphyllus* were alert and active from late August to mid June and were generally inactive in July, remaining motionless with wings closely furled. Additional microchiropteran species co-habiting caves in the Pilliga forest were the Large-eared Pied Bat *Chalinolobus dwyeri* and Eastern Cave Bat *Vespadelus troughtoni*.

Key words: Eastern Horseshoe Bat *Rhinolophus megaphyllus*, Brigalow Belt South bioregion, Pilliga forest, roosting, cave, conservation.

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Introduction

The Eastern Horseshoe Bat *Rhinolophus megaphyllus* Gray, 1834 (Rhinolophidae) (Figure 1) has a distribution that includes eastern New Guinea and associated islands and eastern Australia from Cape York Peninsula to Victoria (Flannery 1995a and 1995b; Pavey and Young 2008). Analysis of mitochondrial DNA supports the recognition of two Australian subspecies with a zone of contact in southern Queensland (Cooper *et al.* 1998). In Australia *R. megaphyllus* is generally found on the coastal plain and the seaward slopes of the Great Dividing Range, with a small number of records from the western slopes of the ranges (Dwyer 1966; Hall *et al.* 1975; Hall and Richards 1979; Churchill 1998; Pavey and Young 2008). *Rhinolophus megaphyllus* roosts by day in caves and anthropogenic surrogates such as disused mines, usually in complete darkness but sometimes well into the twilight zone (Dwyer 1966; Churchill 1998; Pavey and Young 2008). Individuals forage for flying insects by night in a variety of wooded habitats including closed forest, open forest, woodland and coastal scrub and tend to avoid open areas (Pavey 1998; Pavey and Burwell 2004).

This paper describes caves used as diurnal roosting sites by *R. megaphyllus* in the Pilliga forest, near Coonabarabran in northern inland New South Wales (NSW), and documents information on the level and pattern of usage of these caves. The general occurrence of the species in the Pilliga forest is also described. This area is of particular interest as being on the western, inland margin of the

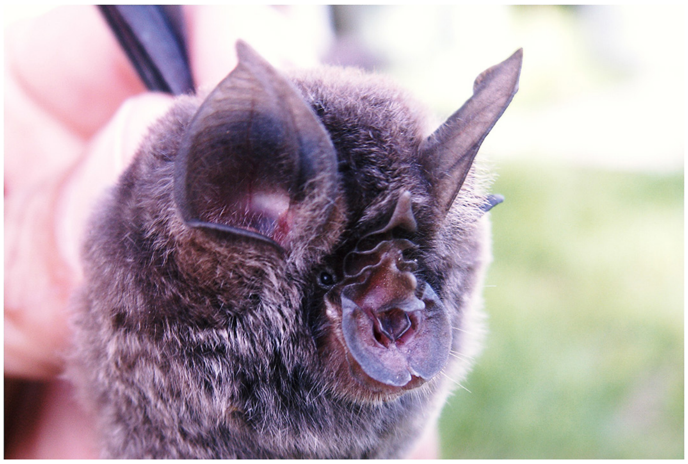

Figure 1. Eastern Horseshoe Bat *Rhinolophus megaphyllus* (adult male) from the Pilliga forest, northern inland NSW. Photo, M.J. Murphy, March 2006.

species' Australian distribution in a relatively dry and nutrient-poor environment. *Rhinolophus megaphyllus* was first recorded in the Pilliga forest in April 1982 (G. Hoye pers. comm. 2013), a western extension of the species' known range. Parnaby and Hoye (1997) described the species as uncommon and sporadically distributed in the Pilliga forest. Prior to the present study there was no published information concerning the species' diurnal roost site selection in this area.

Study area and methods

The Pilliga forest (30°25'-31°15'S, 148°40'-149°50'E) is located in *Gamilaraay* Aboriginal Country in the Brigalow Belt South bioregion (Thackway and Creswell 1995) on the western slopes of the Great Dividing Range in northern inland NSW and is between 290 and 420 km inland from the Australian east coast. The climate is temperate with a summer-dominant rainfall pattern, an annual rainfall of about 600-750 mm and a temperature range between an average monthly minimum of about 2°C in July to an average monthly maximum of about 34°C in January (Weatherzone 2012). The geology is dominated by coarse sandstones of Jurassic to Cretaceous age (Pilliga Sandstone and Keelindi Beds) in the south-eastern Pilliga forest, eroding as a compound alluvial outwash fan towards the north and west. The south-eastern Pilliga forest has an undulating terrain with low rocky ridges and wide sandy valleys, many of the ridges featuring escarpments, rock overhangs and shallow caves. The northern and western Pilliga forest has a flat terrain with no rock outcrops. The Pilliga forest comprises a mosaic of woodland and open forest communities with various *Eucalyptus, Angophora, Callitris, Corymbia, Acacia* and *Allocasuarina* species. Readers are referred to Benson *et al.* (2010) for more detailed information concerning the area's vegetation communities. The majority of native vegetation on more productive clay and loam soils in the surrounding area has been cleared for agriculture, with the Pilliga forest left as a large woodland remnant on the poorest sandy soils. The Pilliga forest totals about 450 000 ha in area and is significant as one of the largest surviving woodland remnants in the modern agriculture-dominated landscape of the Great Dividing Range's western slopes bioregions.

This paper describes seven caves in the Pilliga forest where diurnal roosting by *R. megaphyllus* has been recorded. Three roosts were located by the author over the period 2007-2008. Systematic concurrent (same day or consecutive days) inspections of these caves were made during daylight hours on four occasions over the period April 2010 to July 2011 to assess consistency of use and provide an estimate of minimum total population size across the three caves. The original intention was to complete these concurrent inspections within a single 12 month period; however, *La Niña* conditions in 2010 hindered access in some seasons. The fourth roost was identified by the author in 2012. The fifth and sixth roosts were identified through discussion with NSW National Parks and Wildlife Service and NSW Environment Protection Agency staff (R. Cass pers. comm. 2013; M. Pennay pers. comm. 2013) and the seventh cave was identified by the author in 2013. On each inspection when *R. megaphyllus* was observed the number of bats present, their location in the cave and their level of activity was recorded. Cave attributes including location, aspect, topographic position, elevation, entrance dimensions, internal dimensions and surrounding vegetation were recorded for each cave, as well as information on any other bat species or other fauna species utilising the cave. Observations made during opportunistic diurnal visits to the caves over the period 2007-2014 were also recorded. Observations of bat activity were also made at dusk at two of the caves in late April 2013. Bats were not handled during inspections and, in the case of caves 1, 3 and 7 where approach was restricted due to cave dimensions, were viewed at a distance using a 30 w or 50 w torch and 7 x 50 7.2° binoculars.

The general distribution of *R. megaphyllus* in the Pilliga forest was examined by collating records from the NSW Office of Environment and Heritage Atlas of NSW Wildlife database (data accessed 17 March 2013), consultation with other bat researchers who have worked in the Pilliga forest (H. Parnaby, G. Hoye, M. Pennay, M. Irvin and B. Law) and observations by the author (Murphy pers. obs.).

Results

Roost cave locations and attributes

The location of the seven caves used as diurnal roosts by *R. megaphyllus* are shown in Figure 2, with the caves numbered according to the author's sequence of discovery of roosting. Caves 1, 2, 4 and 7 were in a cluster in the south-central part of the Pilliga forest. Caves 4 and 7 were located in the same rock outcrop and were only 35 m apart. Cave 5 was located in the southern Pilliga forest 24 km south of this cluster. Caves 3 and 6 were less than 2 km apart and were located on the eastern edge of the forest 37 km from the nearest other roost.

Attributes of the seven roosting caves are summarised in Table 1 and photographs of the seven cave entrances

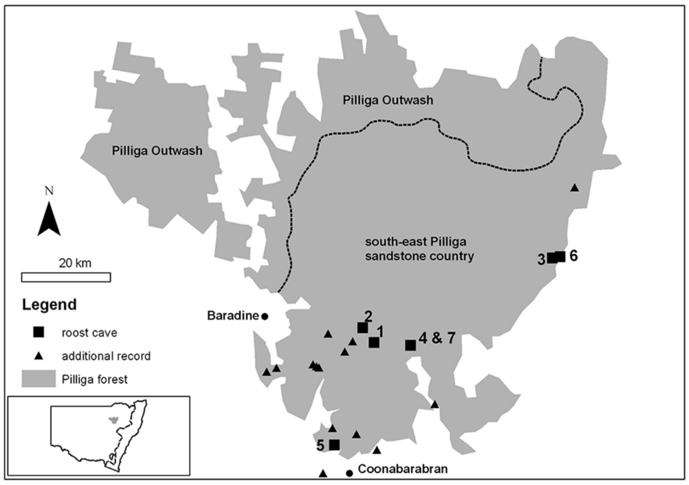

Figure 2. Main map: the Pilliga forest, showing the location of the seven roost caves identified and additional records of *Rhinolophus megaphyllus*. The dotted line marks the boundary between the south-eastern sandstone country and the outwash plain. Inset map: the location of the Pilliga forest in northern inland NSW, west of the Great Dividing Range (dotted line).

Table 1. Cave attributes of *Rhinolophus megaphyllus* roosts located in Pilliga forest.

	Aspect and position of cave entrance	Dimensions of cave entrance	Internal dimensions of cave	Surrounding vegetation
Cave 1	Main entrance WSW aspect and 2nd small entrance W aspect. Entrances 8 m apart at same level on mid slope of hill. Elevation 500 m (Australian Height Datum).	Main entrance 5.3 m wide × 2.2 m high. About half of entrance obstructed by large rock. 2nd small entrance 2.3 m wide × 0.45 m high.	Chamber 8.1 m wide 10 m in from main entrance, widening to estimated 15 m wide further in. Height averages 1.5 m 1st 9 m into cave, decreasing to about 0.45 m remainder of cave. Visible section of cave estimated 25 m deep, disappearing around inaccessible corner at back.	Open forest of *Eucalyptus fibrosa, Corymbia trachyphloia* and *Callitris endlicheri.*
Cave 2	SSE aspect on mid slope of hill. Elevation 440 m (AHD).	4.8 m wide × 0.8 m high. Entrance is at central back of large overhang 16.8 m wide × 3.3 m high × 5.3 m deep.	Low section 4.8 m wide × 0.8 m high × 4.15 m deep leading to larger domed chamber 8.7 m wide × 11.95 m deep × 3.9 m high (maximum height in centre of chamber).	Open forest of *E. fibrosa, C. trachyphloia* and *C. endlicheri.* Woodland of *Angophora floribunda* and *Callitris glaucophylla* along creek within 100 m of cave.
Cave 3	WSW aspect on mid slope of hill. Elevation 420 m (AHD).	4.5 m wide × 2.2 m high.	1st chamber 5.2 m wide × 11.0 m deep × 1.5 m high. Low opening at ground level at rear of 1st chamber leads through 1.6 m wide × 0.30 m high × 2.0 m deep low passage to 2nd chamber 0.57 m high × estimated 10 m wide × estimated 17 m deep. Left rear of 2nd chamber out of view behind rocks.	Open forest of *C. trachyphloia, Eucalyptus crebra, Eucalyptus racemosa, E. fibrosa, C. endlicheri* and *Acacia cheelii.*
Cave 4	NE aspect on mid slope of hill. Elevation 480 m (AHD).	8.7 m wide × 2.5 m maximum height. Entrance is at back of large overhang 9.6 m wide × 5.0 m high × 2.3 m deep.	Main chamber 8.3 m wide × 10.0 m deep × 1.4 m high. Height decreases towards rear and sides where several tunnels at floor level about 1.0 m wide × 0.2 m high extend beyond view.	Open forest of *C. trachyphloia, E. fibrosa* and *C. endlicheri.*
Cave 5	NNW aspect on mid slope of hill. Elevation 540 m (AHD).	4.0 m wide × 1.0 m maximum height.	Low section 4.0 m wide × 0.7 m high × 6.3 m deep leading to larger chamber 9.1 m wide × 14.7 m deep × 3.0 m high (maximum height in centre of chamber). Height decreases towards rear where several tunnels at floor level about 0.40 m wide × 0.20 m high extend beyond view.	Open forest of *Eucalyptus macrorhyncha, C. trachyphloia* and *C. endlicheri.* Woodland of *A. floribunda, Eucalyptus chloroclada* and *Brachychiton populneum* on valley floor within 50 m of cave.
Cave 6	Cave extends through hill. Main entrance W aspect on mid slope of hill. Elevation 460 m (AHD). Three small secondary entrances N to NNE aspect on upper slope of hill. These 3 entrances are within 7 m of each other. Another separate ancillary cave opens from ground level in western overhang (see text).	Main entrance 4.5 m wide × estimated 8 m high, located at back of large overhang 14.2 m wide × estimated 11 m high × 9.6 m deep. Three secondary entrances 0.4 m wide × 1.3 m high, 1.1 m wide × 0.5 m high and 0.35 m wide × 0.5 m high. Ancillary cave entry 3.1m wide × 1.4 m high.	1st chamber in from main entrance 5.7 m wide × 8.4 m deep × estimated 12 m high. Narrow opening at the rear of this chamber leads through 1 m wide × 2 m deep channel to 2nd chamber (roost chamber) 6.25 m wide × 9.4 m deep × estimated 7 m high. Rear wall of 2nd chamber comprises a jumble of large boulders about 3.6 m deep with narrow gaps leading to the 3 secondary entrances. Additional inaccessible cavities open into the roof of the western overhang and the 1st chamber. Ancillary cave 0.3 m high × estimated 8 m wide × estimated 10 m deep, extending beyond view.	Open forest of *C. trachyphloia, E. crebra, C. endlicheri* and *A. cheelii.* Woodland of *Eucalyptus albens* with semi-evergreen vine thicket understorey within 100 m of cave on eastern side of hill.
Cave 7	NE aspect on mid slope of hill. Elevation 480 m (AHD).	4.7 m wide × 1.15 m high located at back of overhang 4.7 m wide × 3.4 m high × 1.4 m deep.	First part of cave 3.1 m wide × 5.2 m deep × 1.0 m high. Low tunnel at floor level at back of cave, 0.5 m wide × 0.3 m high × estimated 14 m deep (viewable section), disappearing around corner at back.	Open forest of *C. trachyphloia, E. fibrosa* and *C. endlicheri.*

are provided as Figures 3-9. All seven caves were in sandstone and had a generally horizontal orientation. Caves 1-5 and 7 had sandy floors with scattered rocks from previous roof collapse while cave 6 had a rocky floor. Caves 1 and 3 were of similar general shape, relatively deep and wide but with a low to very low roof. Caves 2 and 5 had an igloo-like shape, with a low entrance leading to a higher-roofed internal chamber. The main cavern of cave 4 had a relatively high entrance and high roof, with low tunnels at the back and side at floor level extending

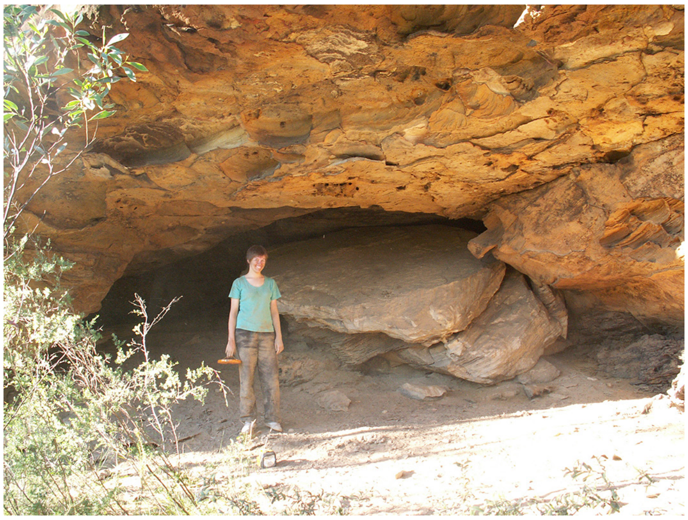
Figure 3. Cave 1 main entrance. Photo, M.J. Murphy, April 2010.

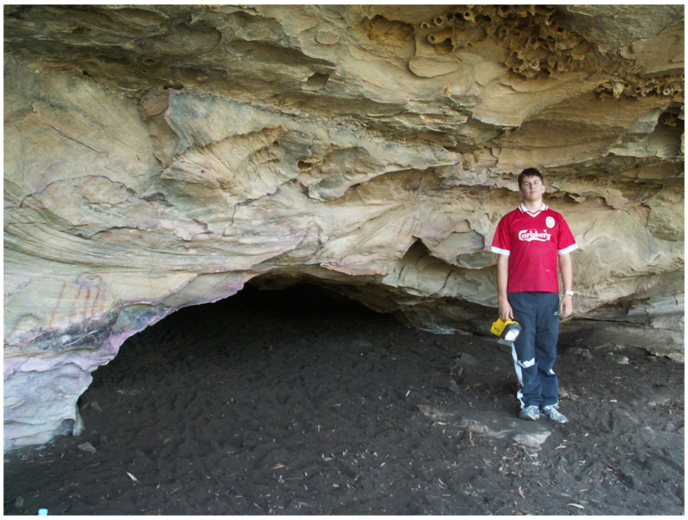
Figure 4. Cave 2 entrance. Photo, M.J. Murphy, April 2010.

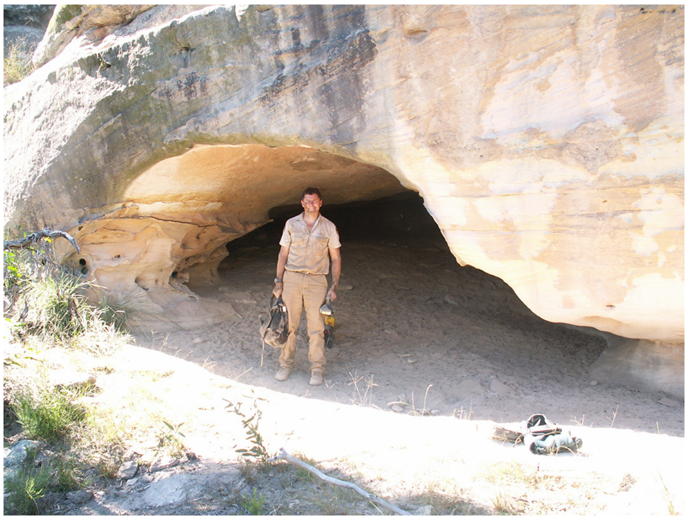
Figure 5. Cave 3 entrance. Photo, J.K. Murphy, April 2010.

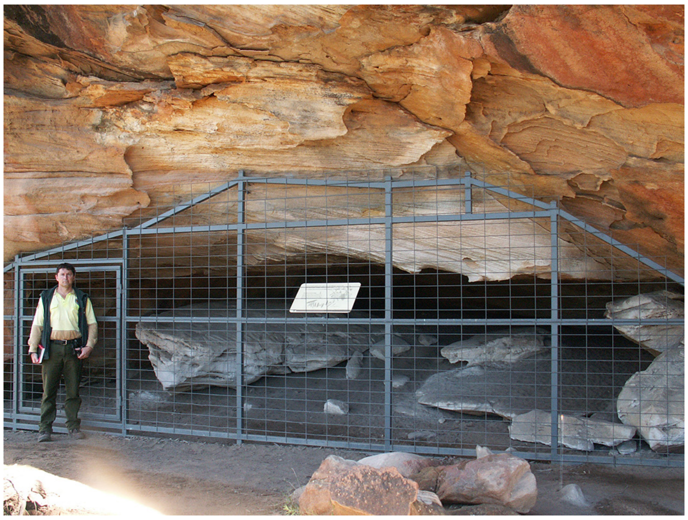
Figure 6. Cave 4 entrance. Photo, J.K. Murphy, July 2012.

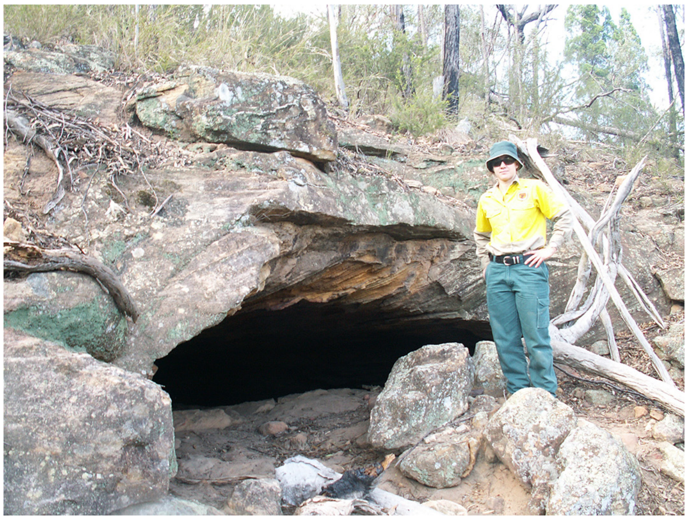
Figure 7. Cave 5 entrance. Photo, M.J. Murphy, March 2013.

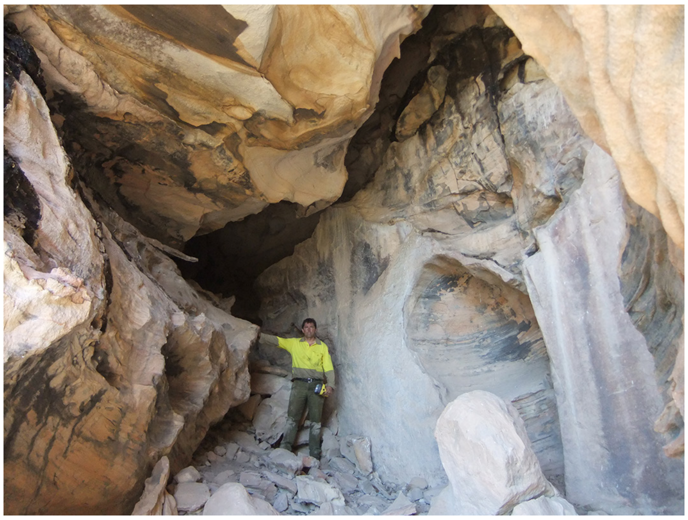
Figure 8. Cave 6 main entrance. Photo, J.K. Murphy January 2014.

Table 2. Results of concurrent diurnal counts of *Rhinolophus megaphyllus* in three roost caves in Pilliga forest.

	Cave 1	Cave 2	Cave 3	Total count
Autumn	0 on 17-Apr-2010	2 on 18-Apr-2010	7 on 17-Apr-2010	9
Spring	1 on 21-Oct-2010	1 on 21-Oct-2010	6 on 21-Oct-2010	8
Summer	5 on 19-Feb-2011	1 on 19-Feb-2011	5 on 19-Feb-2011	11
Winter	4 on 30-July-2011	2 on 30-July-2011	5 on 30-July-2011	11

beyond view. Cave 4 is located immediately adjacent to a popular tourist walking track and had a steel mesh barrier constructed across the cave entrance in 2009 to exclude human access and protect Aboriginal axe grinding grooves within the cave from vandalism or inadvertent damage. Cave 6 had a cathedral-like shape with a high to very high roof. Another smaller ancillary cave located in the same overhang as cave 6 was of the deep, wide and very low-roofed type. Cave 7 had a moderately-sized opening which rapidly narrowed to a long low tunnel shape. In caves 3, 4 and 6 bats roosted in inner chambers accessed from the outer chamber via a restricted passage (Figure 10).

Roost cave usage

The results of concurrent diurnal counts in caves 1, 2 and 3 in 2010-2011 are provided in Table 2. *Rhinolophus megaphyllus* was observed on 11 of the 12 systematic inspections (92%), the exception being the April 2010 visit to cave 1. This cave extended beyond the viewable area and it was subsequently discovered that even minor noise at the cave entrance sometimes resulted in bats retreating out of view and that the cave had to be examined promptly on arrival on site. It is therefore possible that bats were present but unseen on this first occasion. The greatest congregation of *R. megaphyllus* seen in a single cave during these concurrent counts was seven bats in cave 3 in April 2010. The sum of concurrent counts gave a minimum combined population estimate of between eight and eleven bats for these three caves over the 15 month period (Table 2).

Additional opportunistic diurnal counts of *R. megaphyllus* in the seven caves are provided in Table 3, including the first record of roosting in each cave and records provided by other workers. It is noteworthy that over the period mid May to late August 2012 cave 2 had substantially more bats (up to nine) than the one to two recorded there over the course of the 2010-2011 concurrent counts. About five of the nine bats seen in cave 2 on 12 June 2012 were about two-thirds of adult size and were presumably immature animals from the previous spring/summer breeding season. Similarly, one of the two bats seen in cave 6 on 20 April 2013 was a smaller animal. The bats seen in cave 3 in November 2011 and over November 2013 to early January 2014 (Table 3) were notably rotund adults and were considered likely to be pregnant females.

All of the caves except cave 2 had areas inaccessible to humans due to restricted dimensions (caves 1, 3, 4, 5, 7 and ancillary cave 6) or high roof (main cave 6) (Table 1). Observations at dusk at two of these caves (caves 4 and 7) on 24 April 2013 showed that bats were using inaccessible areas of the caves for diurnal roosting. At cave 4 about eight unidentified bats emerged at dusk from low tunnels at floor level in the walls of the main cavern. Two perched momentarily in the main cavern, allowing identification to be confirmed as one *R. megaphyllus* and one Eastern Cave Bat *Vespadelus troughtoni* (Vespertilionidae). At cave 7 about five unidentified bats flew into view from the rear of the low tunnel at dusk, proceeding to fly up and down the length of the tunnel before leaving the cave. Three perched in view at the same time for a short period, hanging from the roof of the tunnel, enabling confirmation as *R. megaphyllus*. No bats had been visible in either cave about an hour before dusk (Table 3).

Information on the roosting location of *R. megaphyllus* in

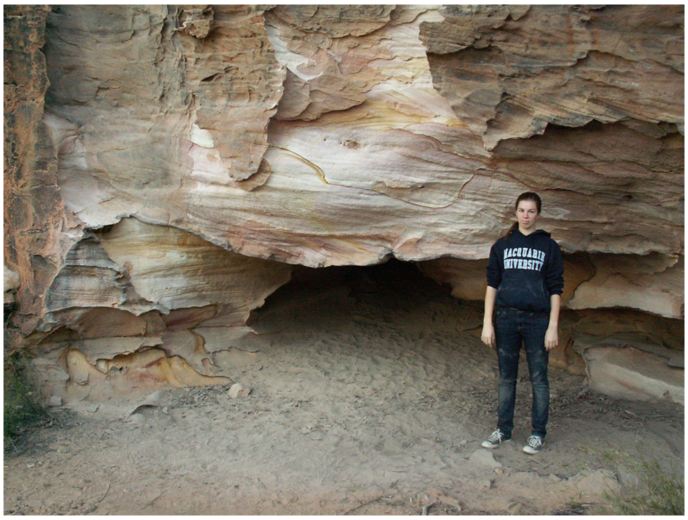

Figure 9. Cave 7 entrance. Photo, M.J. Murphy, April 2013.

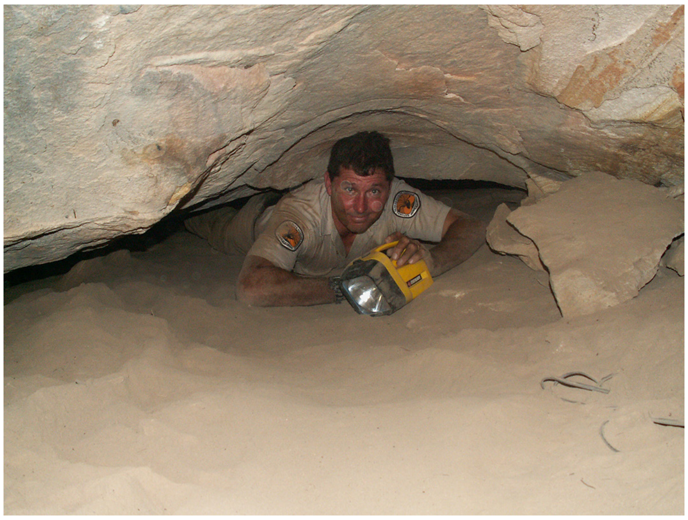

Figure 10. Restricted passage between inner roost chamber and outer chamber of cave 3. The author is shown exiting the inner chamber. Photo, J.K. Murphy, April 2010.

Table 3. Additional opportunistic diurnal records of roosting *Rhinolophus megaphyllus*.

[1]M. Irvin (pers. comm.); [2]G. Hoye (pers. comm.); [3]R. Cass (pers. comm.); [4]H. Parnaby (pers. comm.); [5]M. Pennay (pers. comm.); *bats subsequently observed emerging from un-viewable section of cave at dusk (see text); #bats observed in ancillary cave not main cave (see text).

	Cave 1	Cave 2	Cave 3	Cave 4	Cave 5	Cave 6	Cave 7
1st record	1 on 13-Jun-2007	1 on 31-May-2008	5 on 1-Sep-2008	1 on 15-July-2012	1 on 10-Sep-2010 [1]	2 (undated) in 1990s [4] #	2 on 6-Apr-2013
Additional records	2 on 21-Mar-2013	1 on 12-Aug-2008	7 on 29-Oct-2009	0 on 24-Apr-2013 *	1 on 1-Dec-2011 [3]	~5 on 13-May-2000 [5]	0 on 24-Apr-2013 *
		1 on 23-Dec-2008	3 on 13-Nov-2011			1 on 23-Mar-2013	2 on 18-Jun-2013
		4 on 18-Aug-2010 [1]	6 on 23-Mar-2013			2 on 20-Apr-2013	
		3 on 5-May-2011 [2]	4 on 20-Apr-2013				
		2 on 16-Sep-2011 [1]	3 on 18-Jun-2013				
		1 on 16-Oct-2011	3 on 26-Nov-2013				
		1 on 3-May-2012	6 on 8-Dec-2013				
		4 on 15-May-2012	4 on 14-Dec-2013				
		5 on 25-May-2012	4 on 25-Dec-2013				
		9 on 12-June-2012	6 on 27-Dec-2013				
		4 on 30-Aug-2012	6 on 11-Jan-2014				
		1 on 31 Dec-2012	5 on 25-Jan-2014				
		1 on 21-Mar-2013					
		1 on 23-May-2013					
		1 on 10-Jun-2013					
		1 on 18-Jun-2013					

the seven caves is provided in Table 4. The darkest parts of the caves were generally used for roosting. Animals always hung by their feet and roosted singly but often in the same area of cave. The closest proximity observed was in cave 2 on 12 June 2012, when eight of the nine animals seen were roosting within a 2 m x 2 m area of roof. As noted above, this congregation included about five immature animals. Roosting *R. megaphyllus* were generally alert and active from late August to mid June, regularly rotating the head and sometimes briefly flying about in the cave before settling to roost again nearby. Most roosting bats seen in July were inactive, remaining motionless with wings closely furled; however, the four bats seen in cave 1 on 30 July 2011 were alert and active.

Additional vertebrate species recorded using the caves are also listed in Table 4. Cave 2 is used as a maternity roost by the Large-eared Pied Bat *Chalinolobus dwyeri* (Vespertilionidae) (Murphy pers. obs.; M. Irvin pers. comm. 2014) and also occasionally by small numbers (up to four) of roosting *Vespadelus troughtoni* (Murphy pers. obs.). Cave 4 was used by *V. troughtoni* as noted above. Cave 5 is a known maternity roost of *C. dwyeri* (Pennay 2008). Cave 6 was used by roosting *V. troughtoni*, with five animals found in the second (inner) chamber in March 2013 (Murphy pers. obs.). Limited accessibility prevented searching of caves 1, 3, 6 (ancillary) and 7 for roosting vespertilionid bats. In addition to the range of vertebrate fauna species listed in Table 4, caves 2 and 6 also had the large moth *Dasypodia selenophora* (Noctuidae) recorded co-habiting the bat roosting chambers by day.

Local distribution of species

Figure 2 also shows the spatial distribution of additional records of *R. megaphyllus* in the Pilliga forest. The majority of these records came from harp-trapping or ultrasonic detection night surveys, with one record of a bat caught by

Table 4. Diurnal roosting location of *Rhinolophus megaphyllus* and other vertebrate species recorded in caves. [1]Pennay (2008); [2]R. Cass (pers. comm.); *introduced species.

	Roosting location of *R. megaphyllus* in cave	Other bat species recorded in cave	Other vertebrate species recorded in cave
Cave 1	Usually hanging from roof about half-way into cave, sometimes close to cave wall and at other times in centre of roof. On one occasion a bat was hanging from the low roof only 2 m inside the 2nd small entrance, retreating further into cave when disturbed. Note any animals roosting around corner at rear of cave would not be visible. On one occasion two bats appeared in flight from around corner and then returned there.	Nil	*Hirundo neoxena* *Petrochelidon ariel* Macropodid sp. *Canis lupus* *Capra hircus* *
Cave 2	Usually hanging from roof of domed chamber, either the centre of the roof or close to a side wall. On two occasions single animals were found hanging from the underside of rock pile within 30 cm of cave floor.	*Chalinolobus dwyeri* *Vespadelus troughtoni*	*Underwoodisaurus milii* *Varanus* *Hirundo neoxena* *Eopsaltria australis* *Tachyglossus aculeatus* *Macropus giganteus* *Wallabia bicolor* *Rattus rattus* * *Vulpes vulpes* * *Capra hircus* *
Cave 3	Usually hanging from roof towards rear of 2nd chamber (darkest part of cave). On one occasion one animal was hanging from the roof just inside the 2nd chamber before retreating to the rear of the chamber.	Nil	*Underwoodisaurus milii* *Geopelia striata* *Phaps chalcoptera* *Strepera graculina* *Tachyglossus aculeatus* *Vombatus ursinus* *Macropus rufogriseus* *Wallabia bicolor* *Vulpes vulpes* * *Capra hircus* *
Cave 4	On one occasion one animal (in torpor) hanging from low roof close to wall just over half-way into main chamber, above entrance to a low tunnel. On another occasion bats were presumably roosting out of view in this tunnel and were observed exiting tunnel at dusk.	*Vespadelus troughtoni*	*Varanus* *Hirundo neoxena* *Tachyglossus aculeatus*
Cave 5	Hanging from roof in low tunnel at back of cave on one occasion (M. Irvin pers. comm.) and from highest part of roof in main chamber on another (R. Cass pers. comm.).	*Chalinolobus dwyeri*	*Hirundo neoxena* *Tachyglossus aculeatus*[1] *Vombatus ursinus*[2] *Petrogale penicillata*[1] *Macropus robustus*[2] *Wallabia bicolor*[2] *Rattus rattus* *[2] *Vulpes vulpes* *[2]
Cave 6	Hanging from roof in 2nd chamber of main cave (darkest part of cave), either at the centre of the roof or close to a side wall. Also observed once roosting in ancillary cave (H. Parnaby pers. comm.)	*Vespadelus troughtoni*	*Falco peregrinus* *Hirundo neoxena* Macropodid sp. *Sus scrofa* * *Capra hircus* *
Cave 7	Diurnal roost site out of view at end of long, low tunnel. Bats occasionally seen by day, flying into view and then disappearing at rear of tunnel and one bat seen once roosting in view at end of viewable section. On one occasion at dusk bats appeared at rear of tunnel, flying back and forth along viewable section of tunnel and temporarily hanging from roof ⅓ to ½ way along tunnel, before exiting cave.	Nil	Macropodid sp.

Table 5. Temporal distribution of *R. megaphyllus* records in the Pilliga forest. See text for sources.

Season	Spring			Summer			Autumn			Winter		
Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Diurnal cave roosting	3	5	2	7	2	3	4	5	7	6	4	3
Additional records	1	1	1		1		5	8		6		

hand by the author after it was found active inside a house at night (Fig. 1). All *R. megaphyllus* records are restricted to the sandstone country of the south-eastern Pilliga forest. Collation of the temporal distribution of all records (roosting records plus additional records) is summarised in Table 5 and shows that the species has been recorded in the Pilliga forest throughout the year.

Discussion

The information presented in this paper indicates that *Rhinolophus megaphyllus* is an uncommon resident species in the Pilliga forest. The core of the species' distribution in the Pilliga forest coincides with the most topographically rugged areas; the gorge/escarpment country of the south-central and southern Pilliga and the rocky hills of the Willala/Pantons area on the forest's eastern edge. The lack of records from the western and northern Pilliga forest (Pilliga Outwash) is presumably in large part due to the absence there of rock outcrops providing potential diurnal roosting sites.

The numbers of bats recorded at diurnal roosts in this study were only small (maximum of nine) but are generally typical for this species. The observations at dusk demonstrated that bats were also roosting in out-of-view areas of caves and that the count data provided in Tables 2 and 3 should be considered indicative of minimum estimates of the actual numbers present. *Rhinolophus megaphyllus* colonies are usually less than 10 bats and seldom more than 50 (Dwyer 1966; Pavey and Young 2008). Males tend to be sedentary, living in small colonies and at most moving between a few roosts within a highly localised area, while females are more mobile, congregating in numbers of about 15 to over 2000 (including young) in special maternity caves during the spring and summer and then moving to male colonies after the young are weaned (Dwyer 1966; Hall *et al.* 1975; Young 2001; Pavey and Young 2008). *Rhinolophus megaphyllus* has been recorded foraging at distances of up to 2.25 km (straight-line distance) from their roost (Pavey 1998) and females have been recorded moving as much as 20 km between non-maternity roosts and maternity sites (Dwyer 1966). It is expected that additional diurnal roost caves used by *R. megaphyllus* remain to be found in the south-eastern Pilliga forest. The variation in the number of bats counted in cave 2 (an easily accessible cave so that there was confidence in completeness of counts) over the period May-December 2012 gives an indication of frequent movements between this cave and unidentified caves probably in the immediate local area.

The location of *R. megaphyllus* maternity sites remains largely unknown in many areas (Young 2001; Slade and Law 2007). The closest known maternity cave identified by Dwyer (1966) is near Ashford, 175 km north-east of the Pilliga forest. The present study did not confirm any of the identified roost caves in the Pilliga forest as maternity sites for *R. megaphyllus*. Caves 1, 3, 6 (ancillary) and 7 had very limited human accessibility due to the low roofs, however, and it is possible that more was happening in these relatively deep caves than could be observed. Similarly, inaccessible chambers opening into the high roof of main cave 6 and the wall of cave 4 might be used. The accessible bat roost chamber inspected in cave 6 is not considered a likely maternity roost location as the arrangement of cave entrances results in air flows within the chamber (Murphy pers. obs.), which would prevent maintenance of a high humidity relative to the outside environment. The observations of rotund *R. megaphyllus* in cave 3 near the start of the breeding season in 2011 and during the 2013-2014 breeding season suggests that this cave may indeed be a small-scale maternity site, although it is also possible the bats seen there may have been about to depart to a separate as-yet-unknown larger maternity colony. No roosting bats carrying young were seen. It is considered likely that one or more unidentified maternity caves remain to be found in the Pilliga forest. Based on the distribution of known diurnal roost caves and assuming a 20 km limit to movement between roost caves and maternity caves (Dwyer 1966), it is possible that there are at least two maternity caves in the Pilliga forest, one in the south-central to southern part of the forest (used by bats from caves 1, 2, 4, 5 and 7) and another in the east (used by bats from caves 3 and 6). Given the uncommon local status of *R. megaphyllus* (Parnaby and Hoye 1997; this study), it is estimated that maternity colony size in the Pilliga forest is likely to be in the range of 10-40 animals.

The seven diurnal roost caves reported here ranged in size with depths of between 10-30 m and roof heights of roost chambers of between 0.3-7 m. A wide range of *R. megaphyllus* roost sites have been reported in the literature, including small (3 m deep) to large caves (Dwyer 1966; Hall *et al.* 1975; Schulz and de Oliveira 1995), sea caves (Helman and Schulz 1987), derelict mine adits from 15-70 m deep (Hall *et al.* 1975; Young 2001; Slade and Law 2007), buildings (Harrison 1962) and rock piles and road culverts (Churchill 1998). Hall *et al.* (1975) noted that, whilst individual animals sometimes chose relatively exposed roosting sites such as shallow caves, overhangs and houses, most *R. megaphyllus* colonies occurred in relatively closed subterranean roosts with notably high temperatures and humidities. Dwyer (1966) noted that many roosts had small, restricted entrances, which would assist in maintaining stable and equable temperatures and humidities as well as excluding larger predators. All seven caves recorded in the Pilliga forest had either restricted entrances into or restricted dimensions within the identified roosting chamber. In one cave (cave 4) on one occasion a single bat was found (in torpor) roosting in the relatively open and exposed main chamber, close to the entrance to a more restricted inner roost chamber.

The present author participated in an archaeological excavation in cave 2 in May 2012 (Ozark Environmental and Heritage Management 2012). The dig located a microchiropteran skull buried in fine floor deposits 35-40 cm below the current cave floor surface and a mummified whole animal at 30-35 cm. The skull has been identified as a rhinolophid (probably *R. megaphyllus*) and the mummified animal as a juvenile *Chalinolobus* species (probably a suckling *C. dwyeri*) (H. Parnaby pers. comm. 2013). These specimens are indicative of usage of cave 2 by these species over an extended period of time. The specimens have been lodged in the Australian Museum collection (rhinolophid M.45954 and *Chalinolobus* sp. M.45956).

The present study also documented the use of the seven caves by a wide range of other native fauna species including vespertilionid bats, macropodids, wombats, echidnas (in winter torpor), passerines, pigeons, falcons, geckos, goannas and noctuid moths, demonstrating their broader ecological value. Noctuid moths are preyed upon by *R. megaphyllus* within co-habited roosts (Pavey and Burwell 2005).

Feral goats *Capra hircus* (Bovidae) are common and widespread in the Pilliga forest and frequently occupy overhangs and caves, degrading them through wearing of rock surfaces, contamination with faeces and urine and grazing and trampling of surrounding vegetation cover (Murphy pers. obs.). Competition and habitat degradation by feral goats is currently listed as a key threatening process under both the NSW *Threatened Species Conservation Act 1995* and Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (NSW Scientific Committee 2004; Department of Environment, Water, Heritage and the Arts 2008), although the likely adverse impact on cave-roosting bats was not acknowledged. Pennay (2008) noted that the low entrance to cave 5 would deter goats from entering. Similarly the low roof of caves 1, 3, 6 (ancillary) and 7 would deter access to these caves by goats. Cave 2 has a low entrance but is still occasionally used by goats. The first chamber of cave 3 is visited by goats but they are unable to access the low-roofed second chamber used by the bats. Goats have access into the second (roosting) chamber of cave 6 (main cave) but the high roof provides goat-free roosting areas. The occurrence of introduced predators such as the Black Rat *Rattus rattus* (Muridae) and European Red Fox *Vulpes vulpes* (Canidae) at some of the roost caves (Table 4) is also of concern.

The main cavern of cave 4 was easily accessible and, located on a popular tourist walking trail, had a high level of human activity prior to the construction of a steel mesh barrier across the entrance. The barrier, made of 3 mm diameter steel forming rectangular openings 200 mm wide x 100 mm high (see Fig. 6) is pinned to the cave entrance roof at several points but otherwise has a series of narrow gaps along the top. Bats were observed at dusk leaving and entering the cave via one 200 mm high x 600 mm wide gap between the barrier and roof. It is evident that this barrier may possibly hamper but demonstrably does not prevent bat access to the cave. The protection from disturbance by humans (as well as goats and foxes) afforded by this barrier may in fact improve the overall value of this cave as a bat roost site. It is proposed to install a bat window in the steel mesh barrier at cave 4 to facilitate bat access while maintaining protection from disturbance.

The *R. megaphyllus* population in the south-east Pilliga forest is of regional conservation significance as one of only few populations in the western slopes bioregions, on the western, inland edge of the species' Australian distribution. The species has also been recorded nearby in the Warrumbungle National Park to the south-west and Mount Kaputar National Park to the north-east (Atlas of NSW Wildlife data accessed 17 March 2013). Unlike the Pilliga forest, however, these two areas represent westward projections of mesic eastern habitats into the more xeric western slopes and plains. An extensive survey of state forests on the NSW western slopes between Dubbo and the NSW/Queensland border detected *R. megaphyllus* at only one out of 45 sites (Date and Paull 2000). The western slopes bioregions are now a predominantly agricultural landscape, and it is probable that historical large-scale land clearing has adversely impacted on the regional status of *R. megaphyllus*. The species preferentially forages in wooded rather than open habitats and is considered susceptible to clearing or fragmentation of woodland and forest (Pavey 1998; Pavey and Burwell 2004). The hotter, drier conditions and more intense *El Niño* events expected in inland NSW by 2050 as a result of anthropogenic climate change are likely to put further pressure on native biota, particularly species such as *R. megaphyllus* which are at the edge of their climatic range, have sedentary habits, and have specialised thermal requirements in roosts (NSW Department of Environment Climate Change and Water 2010).

Conclusion

This paper has documented a variety of sandstone caves in the Pilliga forest used as diurnal roosting sites by *Rhinolophus megaphyllus*, described the species' local distribution in the Pilliga forest and noted the conservation significance of this edge-of range population. Longer term observations in the identified roost caves and further searching for additional roost sites and particularly maternity sites is needed to better understand the status and conservation management requirements of the species in the Pilliga forest. In the interim, a precautionary approach is appropriate and all known roost caves should be protected from disturbance.

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